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CANADIAN UNDERWATER MINE APPARATUS: UNMANNED PERFORMANCE VALIDATION OF THE SECOND PROTOTYPE SECOND STAGE REGULATOR

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ABSTRACT

The Canadian Underwater Mine Apparatus (CUMA) is a rebreather type apparatus employing a self-contained gas supply system that mixes pure oxygen with a diluent gas. The resultant gas mixture supplied to the counterlung has a constant oxygen partial pressure over the depth range of the apparatus. Operationally, the diluents used are nitrogen for depths up to 55 metres of seawater (msw) and helium to 80 msw. After the evaluation of the first prototype of the CUMA, it was recommended that the second stage regulator in diluent circuit be re-engineered to increase its compatibility with helium and saltwater before open water trials to 80 msw were attempted. The contractor, Fullerton, Sherwood Engineering Limited, produced a new regulator that the Experimental Diving Unit of the Defence and Civil Institute of Environmental Medicine evaluated prior to further manned dives with the CUMA prototype. Apparatus were set up to reproduce the diluent circuit and allow simulation of diving the circuit. Tests of the regulator were repeated three times for each combination of diluent (helium or nitrogen), high pressure supply (500 to 1000 pounds per square inch, gauge (psig) or 2000 to 3000 psig), first stage regulator output setting (140, 155 and 170 psig) and depth (pressures equivalent to 0 to 9 Bar gauge). The results showed a highly linear and repeatable function of the second stage regulator in relation to depth. Additionally, no gas leaks were found in the regulator. It was recommended that the new second stage regulator would be suitable for continued manned evaluations of the CUMA.

INTRODUCTION

The Canadian Underwater Mine Apparatus (CUMA) is under development by the Defence and Civil Institute of Environmental Medicine (DCIEM) and Fullerton, Sherwood Engineering Limited (FSEL) for the Canadian Forces (CF). The apparatus provides life support for a mine-countermeasures diver to depths of 80 metres of seawater (msw). The design of the CUMA, described previously by Eaton [1], produces a breathing gas with constant oxygen partial pressure (P_{O_2}) by mixing pure oxygen (O_2) with a diluent. The diluents used to date include nitrogen (N_2) for diving to depths of 55 msw and helium (He) for depths to 80 msw.

A reliability test of the gas-mixing circuit [2], two manned evaluations of the CUMA in DCIEM's hyperbaric facilities [1], and a field trial at Fleet Diving Unit (Pacific) (FDU(P)) [3] proved that the gas-mixing circuit worked as desired. However, a crucial component in the diluent circuit, the second stage regulator, needed technical improvements to increase its compatibility with saltwater and helium.

FSEL completed these engineering changes and provided DCIEM with a working regulator. The Experimental Diving Unit (EDU) prepared a test protocol to evaluate the output characteristics, and to some extent the reliability, of the new regulator. The regulator operating characteristic should theoretically result in a zero order, linear relationship between output pressure and the depth or signal pressure. This document describes the results of a series of tests that EDU performed to establish the linearity of the regulator, the coefficients of the regression line, and the repeatability of the relationship.

METHODS

Apparatus.

The diluent portion of the gas-mixing circuit was reproduced with the second stage regulator in place as shown in Figure 1. The signal pressure applied to the regulators simulated the depth and was controlled by adjusting a backpressure regulator downstream of the diluent circuit outlet. A secondary regulator, driven by the high pressure supply, produced a signal pressure to initiate gas flow in the diluent circuit. Once flow was initiated the secondary regulator was shut down and the diluent circuit provided the gas to continue pressurization. The 2 litre volume tank helped filter out unwanted transient changes in signal pressure.

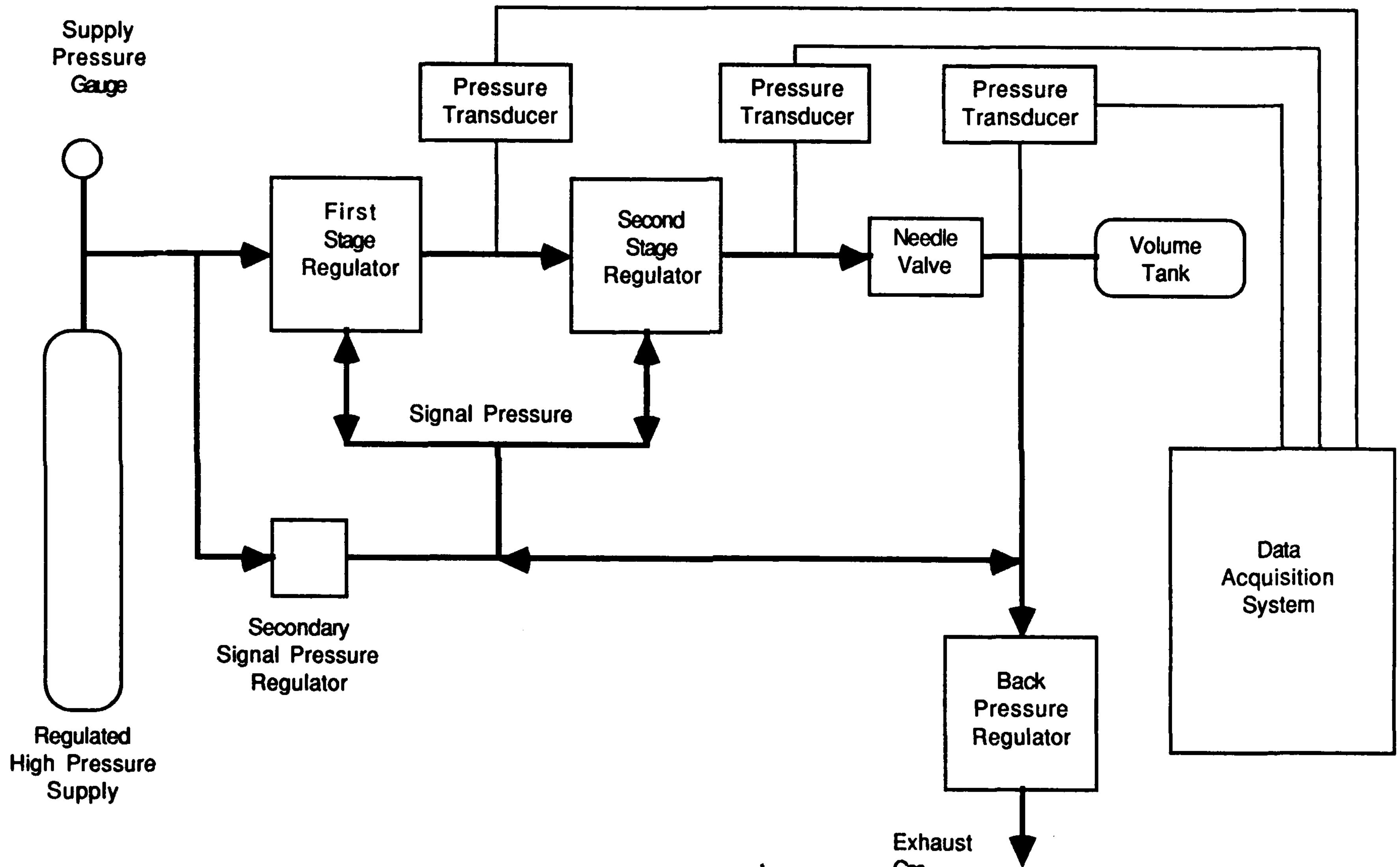

Figure 1. CUMA diluent circuit test setup.

The three pressures, first stage regulator output pressure, second stage regulator output pressure, and signal pressure, were measured using three separate transducers (Validyne, DP-15). All transducers were calibrated prior to the experiment using a dead weight tester (Ametek, HK-70B). A microcomputer (Hewlett-Packard, HP85) was programmed by EDU to record, on digital tape, the three pressures using a scanner (Hewlett-Packard, HP3495A) and a digital multimeter (Hewlett-Packard, HP3455A).

Test Conditions.

Four variables were used to define the test conditions:

a. diluent gases:
   i. nitrogen
   ii. helium
b. gas supply pressure with two ranges:
   i. greater than 500 pounds per square inch (gauge) (psig) and less than 1000 psig
   ii greater than 2000 psig and less than 3000 psig
c. first stage regulator output pressure with three settings:
   i. 140 psig;
   ii. 155 psig; and
   iii. 170 psig;
d. signal pressure with two ranges:
   i. 0 to 9 Bar (gauge) in 1 Bar increments.
   ii. 9 to 1 Bar (gauge) in 2 Bar decrements.

Procedure.

Before the tests commenced the needle valve, Figure 1, was set so that the flow at 9 Bar (gauge) was equal to 18.9 Litres per minute at standard temperature and pressure ($L \cdot min^{-1}$ (STPD)) for helium and 12.2 $L \cdot min^{-1}$ (STPD) at 6 Bar, (gauge) for nitrogen.

Tests commenced by turning on the gas supply, allowing the first stage regulator to stabilize for about 1 min and then recording the no-flow pressures. Using the secondary regulator, the signal pressure was increased to about 0.7 Bar, (gauge). At this point, the diluent circuit would provide enough gas to continue pressurizing the system for the rest of the test. Consequently, the secondary regulator was shut down and the back pressure regulator was used to set the signal pressure. The back pressure regulator was then adjusted to increase signal pressure to 1 Bar, (gauge) ± 0.02 Bar

and the signals from the three pressure transducers were recorded. The signal pressure was increased in 1 Bar increments until 9 Bar, (gauge) was reached. At each setting the three pressures were recorded. The signal pressure was then decreased in 2 Bar increments until 1 Bar, (gauge) was reached with the three pressures being recorded after each change. The test was concluded after recording the pressures at 1 Bar, (gauge). Each condition was repeated three times.

Analysis.

The data were transferred from the microcomputer to DCIEM's central computer facility for analysis using the S software system (Qualtec). Separate linear regressions of the first and second stage output pressure versus signal pressure were completed.

RESULTS

For both He and N_2 diluents, variations between repetitions and between the two gas supply pressure ranges were minimal. Additionally, the first stage regulator setting had no detectable influence on second stage regulator output. Therefore, these data were also combined resulting in the two regression lines of second stage output versus signal pressure (Figure 2 for He and Figure 3 for N_2).

The data for the three repetitions at each condition and for the two gas supply pressures were combined to produce the three regression lines of the first stage regulator output versus signal pressure for helium in Figure 4 and for nitrogen in Figure 5.

Neither helium nor nitrogen leaked through the diaphragms or seals during the tests.

DISCUSSION

From Figure 2 and 3 the consistency of the second stage regulator output in relation to depth over all the conditions is obvious. This is extremely desirable, since the test conditions define the expected range for normal operation. The less sensitive the ratio regulator is to changes in inputs other than depth, the more predictable is its performance. Similarly the first stage regulator output is very linear and shows little variability. Stability in first stage regulator output further ensures predictable performance at the second stage.

FSEL determined the slope of the regression line to be 1.88 which is higher than the 1.84 found in this study, but not appreciably different when considering the operational calibration of the CUMA. The intercept found by FSEL was 0.34 Bar. The offset in the EDU tests was 0.404 for nitrogen and 0.354 for helium. The offset was not adjusted before the EDU tests. The small difference between the results could not

be explained except through possible differences in instrumentation accuracy or perhaps drift in the regulator offset.

The design and construction of the second stage regulator produced by FSEL solved the gas leakage problems associated with the first prototype regulator [1]. The corrosion problems with the first regulator's aluminum housing [3] were eliminated through the use of a Delrin housing. (Delrin is an acetal resin from DuPont).

CONCLUSIONS AND RECOMMENDATIONS

The new second stage regulator performs as expected. The output is very linear with depth and is reliable over a wide variety of conditions. Now that the gas leakage problem has been corrected, it is recommended that the manned trials continue with the ultimate goal being open water dives to 80 msw.

Although this regulator performed well, no statement can be made concerning the inter-regulator variability. This will have to be determined once a representative sample of production-grade models are available.

ACKNOWLEDGEMENTS

The author would like to thank the project diver, PO1 G. Cox for the tedious hours spent collecting this data and the project technologist, R. MacLean who, as always makes sure all of our essential equipment keeps operating.

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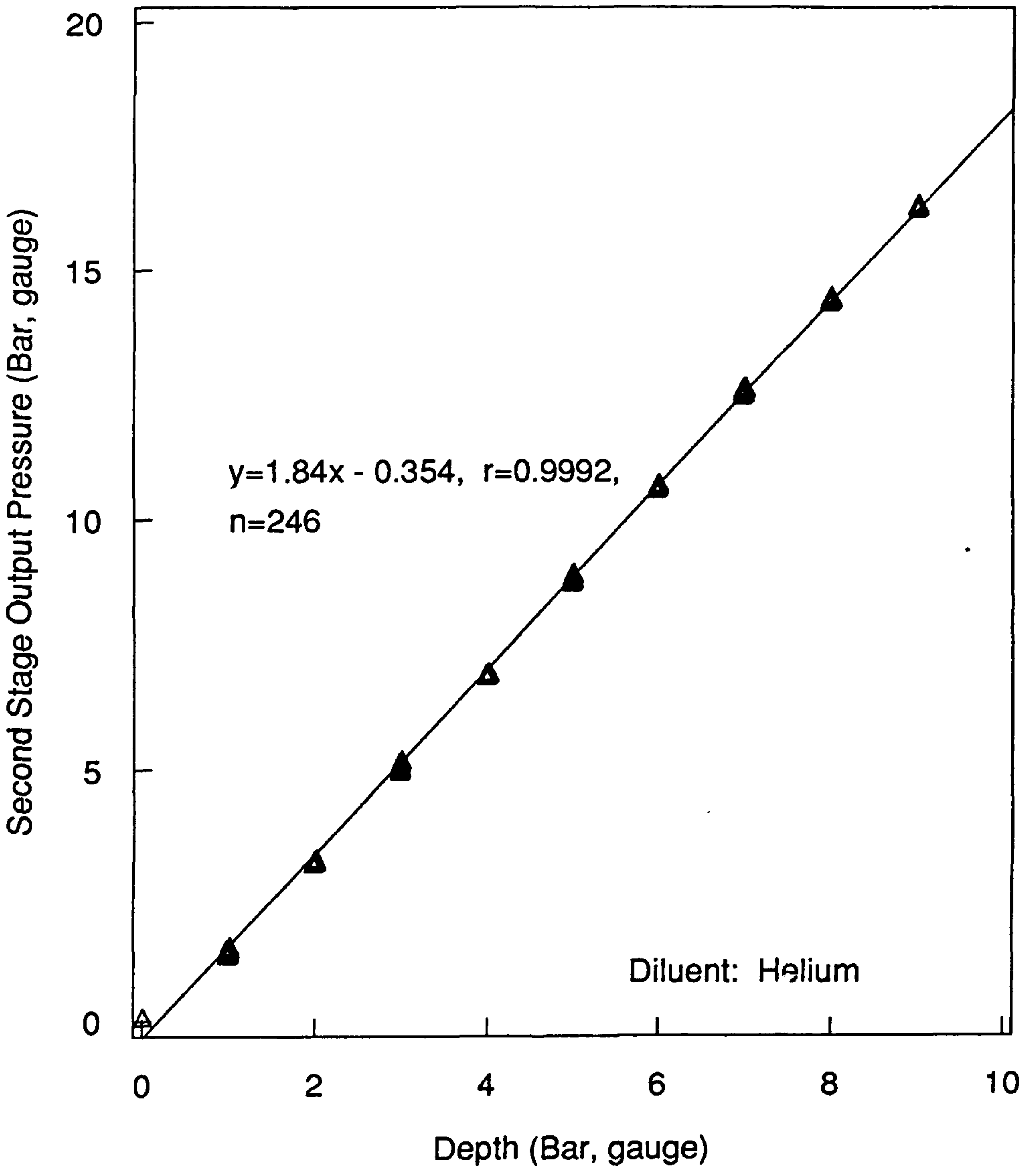

Figure 2. Second stage regulator output pressure as a function of depth using all data points for helium diluent.

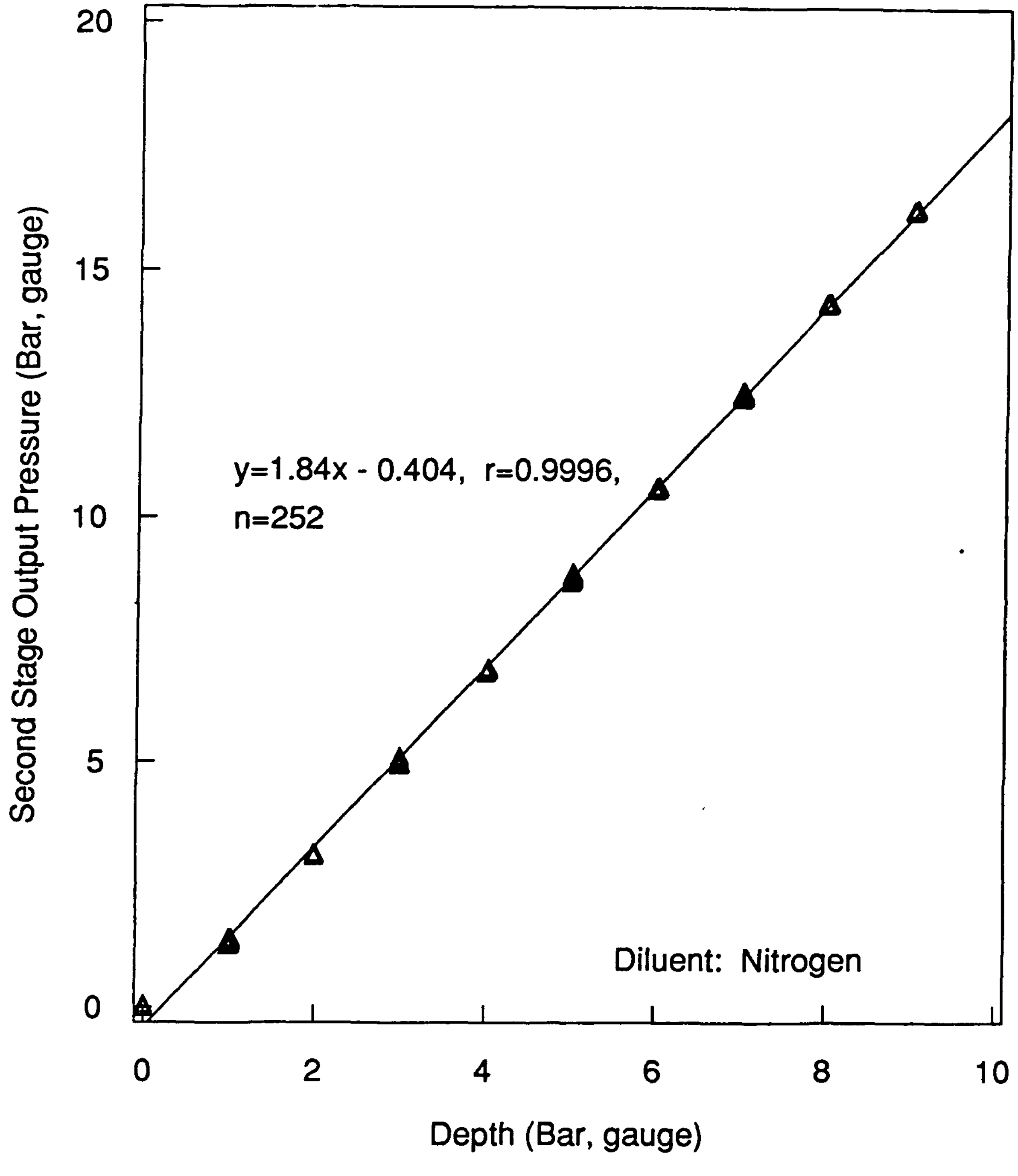

Figure 3. Second stage regulator output pressure as a function of depth using all data points for nitrogen diluent.

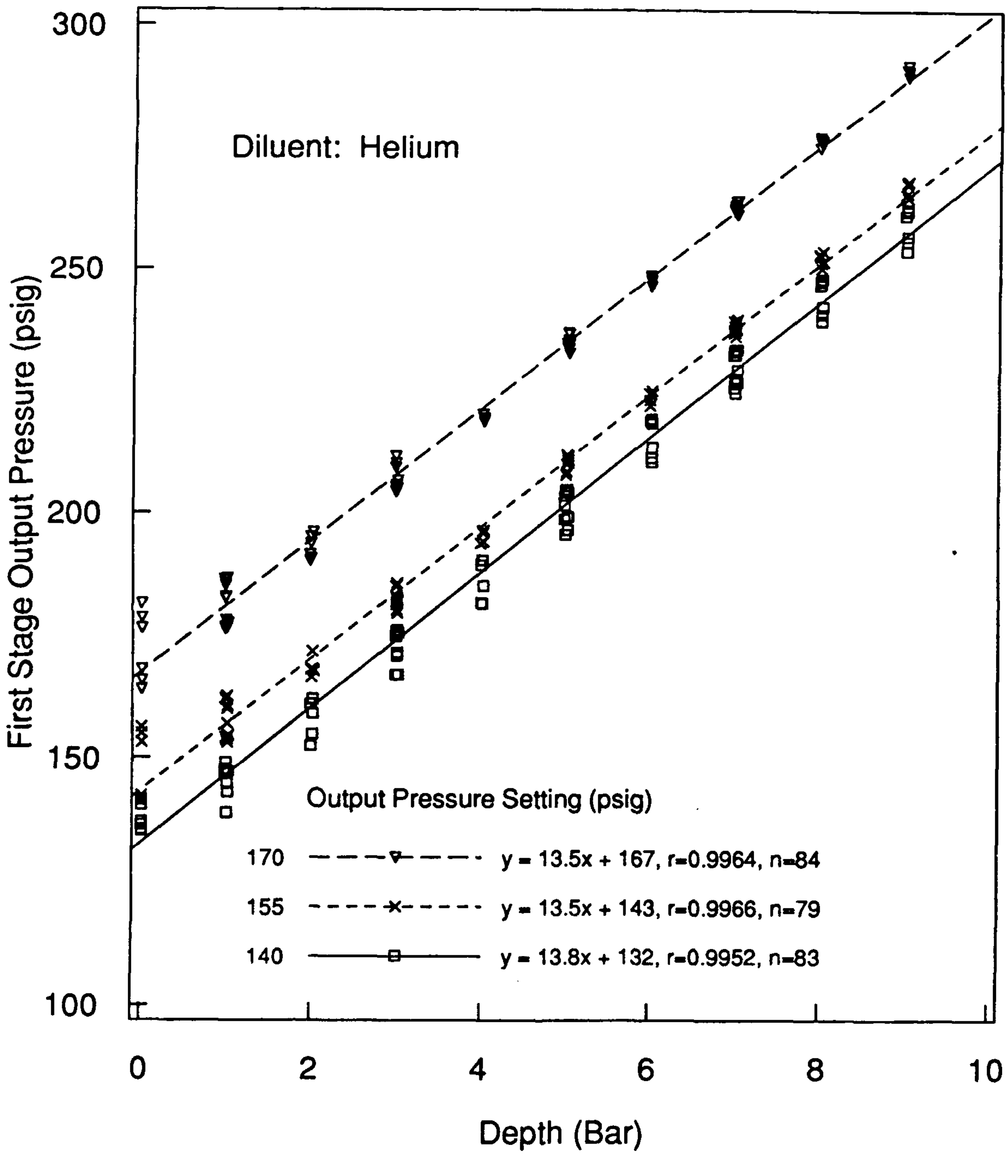

Figure 4. First stage regulator output pressure as a function of depth and regulator setting using helium diluent. All data points are plotted for each regulator setting.

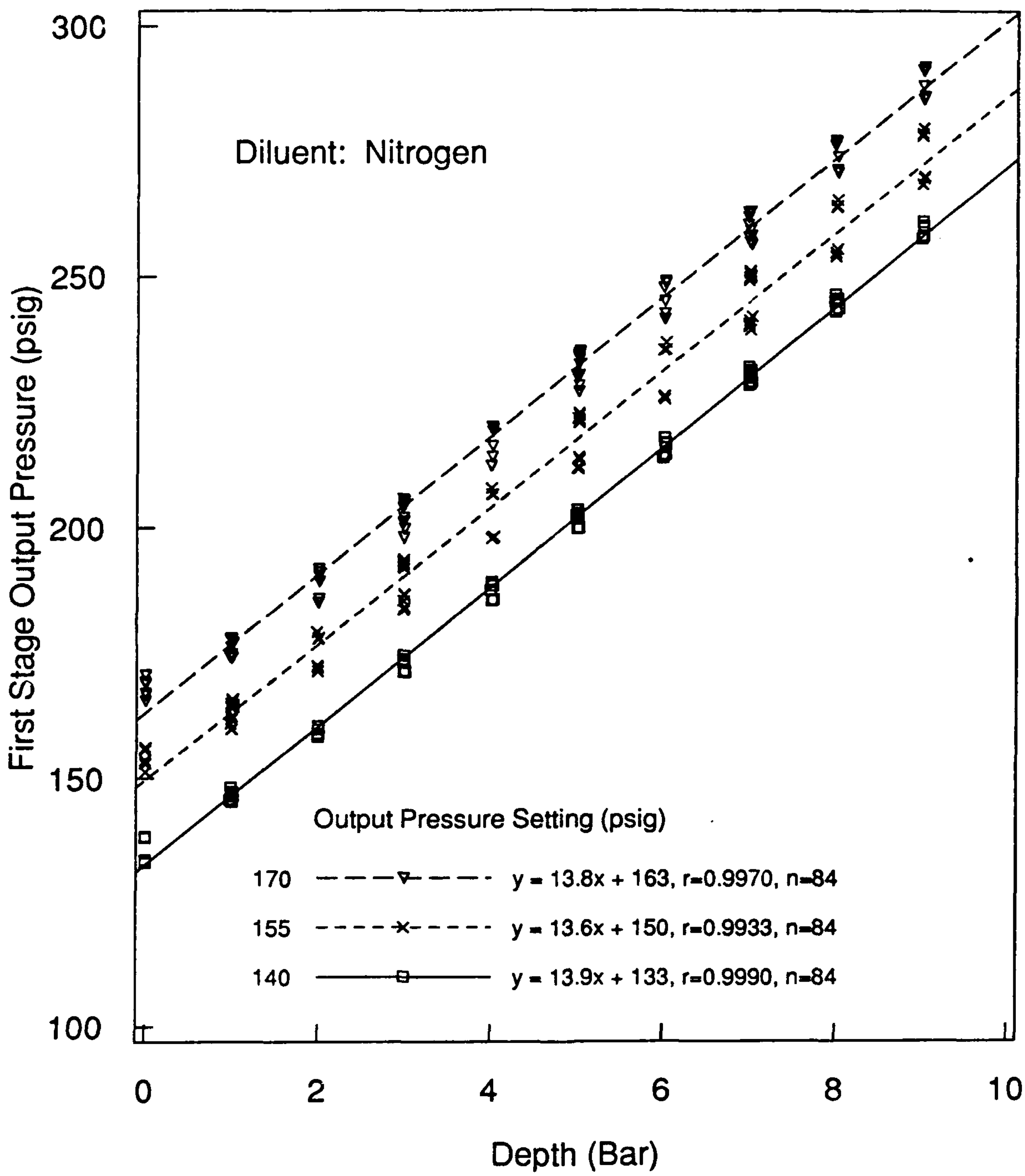

Figure 5. First stage regulator output pressure as a function of depth and regulator setting. using nitrogen diluent. All data points are plotted for each regulator setting.

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